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(54) Spin valve film.

(57) Disclosed is a spin valve film having a first magnetic layer, a non-magnetic layer, a second magnetic layer, and an antiferromagnetic layer as the fundamental structure for the film. In such structure of the spin valve film, a single-layered film or a multi-layered film consisting of CoZrNb, CoZrMo, FeSiAl or FeSi, or a material prepared by adding Cr, Mn, Pt, Ni, Cu, Ag, Al, Ti, Fe, Co or Zn to the above-mentioned substance is used for at least one of the first magnetic layer and second magnetic layer. According to the present invention, a thin spin valve film having a good sensitivity with respect to magnetic field and a significant magnetoresistive effect can be obtained. When using this thin film for a shield reproducing head or a yoke reproducing head, the maximum reproducing output obtainable is approximately four times that of a reproducing head which utilizes the magnetoresistive effect provided by the application of the prior art.

EP 0 674 327 A1

BACKGROUND OF THE INVENTION

Field of the Invention

The present invention relates to a magnetic head which utilizes the magnetoresistive effect.

Description of the Related Art

With regard to the magnetic field sensor which utilizes the variation of the magnetoresistance of a multi-layered thin film formed by laminating magnetic metal and non-magnetic conductive material, an idea is disclosed in the specification of U.S. Patent No. 4,949,039. A spin valve film results from the development of such idea thus disclosed, and it is obtained by fixing the magnetization of a magnetic layer on one side by the provision of an antiferromagnetic layer adjacent to it. Thus, the spin valve film belongs to the subordinate conception disclosed in the U.S. Patent No. 4,949,039. For the spin valve film, the fundamental conception is also disclosed in U.S. Patent No. 5,206,590. In this disclosure, as materials forming each layer of the spin valve film, Co, Fe, Ni, NiFe, NiFe and NiCo are introduced as the thin film layer of the ferromagnetic elements, and Au, Ag, Cu, Pt, Pd, Cr and Ta, as the non-magnetic metallic elements, and FeMn, as the antiferromagnetic layer.

When NiFe is used for the spin valve film using a conventional substrate or base layer, the variation of the magnetoresistive rate for the spin valve film is made greater from 5 to 10%, but the magnetic characteristic of the NiFe varies greatly depending on crystallinity. Therefore, in order to materialize the good sensitivity with respect to magnetic field, it is necessary to reduce the oxygen concentration in a target, and back pressure when forming a film, and to make the temperature of a substrate high and constant. Accordingly, the target purity must be enhanced, and thus, the purchase price of the target is inevitably increased. In order to reduce the back pressure at the time of film formation, a vacuum pump, a chamber and other expensive equipment are required for maintaining a high vacuum condition. Further, while a heater and other equipment are needed in the interior of the vacuum device for raising the temperature of the substrate, a heavy load is applied to the bearing and others provided for the self-revolving equipment to rotate the substrate. Such an arrangement is indispensable to obtaining a thin uniform film. Also, such equipment must be operated at a high temperature, and consequently, the replacement of parts should be made more frequently, leading to an increased running cost. In addition, in order to reduce the back pressure at the time of film formation, the substrate must be left to stand for a long time after it has been set until the film formation begins, and then, the temperature of the substrate is made high in order to form the film. Therefore, after completion of the film formation, a long cooling period is needed until the spin valve film formed on the substrate can be released. To meet these requirements, it is inevitable that the frequency of film formation per unit period should be limited, thus hindering the implementation of its production on a large scale. Therefore, in order to reduce the cost of the film formation, it is necessary to obtain a magnetic material which enables the provision of good crystal more easily than NiFe or to obtain a buffer layer or a substrate on which crystal is easily grown so that NiFe can obtain a good magnetic characteristic if the NiFe should be used eventually.

In the prior art, Cu is used for the non-magnetic layer. In the cases where the Cu is used, it is necessary to increase the purity of the Cu target, to reduce the back pressure at the time of film formation, and to control the temperature of the substrate also at the time of film formation as in the case of the magnetic film. This arrangement inevitably leads to the increased cost of manufacturing. In order to reduce the manufacturing cost, it is required to obtain a non-magnetic material which enables the provision of a good MR characteristic more easily than the Cu. If the Cu should be used, there is a need for the arrangement of a substrate or buffer layer capable of promoting its crystal growth to obtain a good MR characteristic.

According to the prior art, FeMn is actually used as the antiferromagnetic material. While the FeMn and NiFe provide an exchange coupling in a good condition, there is a disadvantage that FeMn is easily subjected to oxidation. Here, in order to enhance reliability, it is necessary to obtain in place of FeMn an antiferromagnetic material which is not easily oxidized in the air and the characteristics of which are not easily deteriorated, or if the FeMn should be used, it is required to provide a protective film to prevent the FeMn layer from being in contact with the air so that it may be oxidized with difficulty.

SUMMARY OF THE INVENTION

It is an object of the present invention to provide a spin valve film which is superior to the conventional one in terms of the reliability and the manufacturing cost, and also, is capable of presenting a higher MR ratio and a better characteristics of the head output than those of the conventional spin valve film.

In a spin valve film having a first magnetic layer/a non-magnetic layer/a second magnetic layer/an antiferromagnetic layer as its fundamental structure of the film, a single-layered film or a multi-layered film formed of CoZrNb, CoZrMo, FeSiAl or FeSi is used for at least one of the first magnetic layer and the second magnetic layer. It may be possible to use for the non-magnetic layer a single-layered film or a multi-layered film formed of a single substance selected from Al, Si, Ti, Ir, V, Cu, Zn, Zr, Nb, Mo, Pd, Ag, Sn, Hf, Ta, W, Pt, Au, Pb, Bi, C and silicon carbide or a mixture thereof. As the antiferromagnetic layer, a single-layered film or a multi-layered film formed of a single substance selected from FeMn, NiO, CoO, FeO, Fe_2O_3, MnO, CrO, Cr and Mn, a mixture thereof, or a material prepared by adding to the substance or mixture Mo, W, V, Ir, Nb, Ta, Mn, Tc, Re, Ru, Rh, Fe, Co, Ni, Pt, Pd, Au, Ag or Cu may be used. For the first or second magnetic layer, a single-layered film or a multi-layered film formed of a material to which Cr, Mn, Pt, Ni, Ir, Cu, Ag, Al, Ti, Fe, Co or Zn is added may be used.

Or, in a spin valve film having a first magnetic layer/a non-magnetic layer/a second magnetic layer/an antiferromagnetic layer as its fundamental structure of the film, at least one of the first magnetic layer and the second magnetic layer is formed of either NiFe or NiFeCo, and for the non-magnetic layer, a single-layered film or a multi-layered film formed of a single substance selected from Al, Si, Ti, Ir, V, Zn, Zr, Nb, Mo, Pd, Ag, Sn, Hf, Ta, W, Pt, Au, Pb, Bi, C or silicon carbide or a mixture thereof is used. In this case, as the antiferromagnetic layer, a single-layered film or a multi-layered film formed of a single substance selected from CoO, FeO, Fe_2O_3, MnO, CrO, Cr and Mn, a mixture thereof, or a material prepared by adding Mo, W, V, Ir, Nb, Ta, Mn, Tc, Re, Ru, Rh, Fe, Co, Ni, Pt, Pd, Au, Ag or Cu to the substance or the mixture may be used. It may be possible to provide a constitution in which the first magnetic layer or the antiferromagnetic layer is in contact with the substrate or the buffer layer formed on the substrate. It may also be possible to arrange a constitution in which a protective layer is provided on the outermost layer.

In addition, at least one of the first magnetic layer and the second magnetic layer may be formed of CoZrNb, CoZrMo, FeSiAl or FeSi, and for the substrate, a single-layered film or a multi-layered film may be formed of glass, ceramic, metal, metallic compound or plastic, or a mixture of these materials. A single-layered film or a multi-layered film formed of a single substance selected from Ta, Hf, Si, Au, Pt, Ag, Cu, Ti, Mn, Cr, Al, Si nitride, Si oxides, Al oxide, AlN, Al nitride, SiC and C or a mixture thereof may be used for the buffer layer. For the protective layer, a single-layered film or a multi-layered film formed of Ta, Hf, Si, Au, Pt, Ag, Cu, Mn, Ti, Cr, Al, Si nitride, Si oxides, Al oxide, Al nitride, SiC, C or diamond-like carbon, or a mixture or alloy of these substances may be used. At least - one of the first magnetic layer and the second magnetic layer is formed of NiFe or NiFeCo, and fundamentally, it may be possible to use a single-layered film or a multi-layered film formed of ceramic, metal, metallic compound or plastic or a mixture of these materials. For the buffer layer, a single-layered film or a multi-layered film formed of a single substance selected from Si, Au, Pt, Ag, Cu, Ti, Mn, Cr, Al, Si_3N_4, Si nitride, SiO_2, Si nitride, Al_2O_3, Al oxide, AlN, Al nitride, SiC, C and diamond-like carbon or a mixture thereof may be used. For the protective layer, a single-layered film or a multi-layered film formed of Ta, Hf, Si, Au, Pt, Ag, Ti, Cr, Al, Si nitride, Si oxides, Al oxide, Al nitride, SiC, C or diamond-like carbon, or a mixture or alloy thereof. The film thickness of at least one of the first magnetic layer and the second magnetic layer may be 5 to 30 nm. The film thickness of the non-magnetic layer may be 2 to 5 nm. The film thickness of the antiferromagnetic layer may be 10 to 100 nm. The film thickness of the metallic protective layer may be 3 nm or less. The film thickness of the non-metallic protective layer may be 2 nm or more. The film thickness of the metallic buffer layer may be 15 nm or less. The film thickness of the non-metallic buffer layer may be 5 nm or more.

CoZrNb and CoZrMo, and a material obtained by adding Cr, Mn, Pt, Ni, Cu, Ag, Ir, Al, Ti, Fe, Co or Zn to CoZrNb or CoZrMo become amorphous when film formation is performed using usual sputtering. Therefore, if any of the above-mentioned material is used for a substrate or a buffer layer, good magnetic characteristics can be obtained even in the case where special attention is not paid to the back pressure during the film formation and target purity as compared to the case where NiFe and others are used. Also, since FeSiAl and FeSi are materials having body-centered cubic structure, and good crystallinity, it is easier to form a film having a good crystal, and obtain a good magnetic characteristic if such materials are used.

Also, when Ag, Au, an alloy of Ag and Au or a material prepared by adding to Ag or Au a single substance selected from Al, Si, Ti, Ir, V, Cu, Zn, Zr, Nb, Mo, Pd, Sn, Hf, Ta, W, Pt, Pb, Bi and C or some of the substances in combination is used for the non-magnetic layer, the current characteristic of the film hardly changes with time because the Ag or Au is a material which is hardly oxidized, and presents a

nature which does not allow the interfacial diffusion to occur easily between the magnetic layer and the non-magnetic layer due to its wettability. Also, when a material prepared by adding to Cu a single substance selected from Al, Si, Ti, Ir, V, Zr, Nb, Mo, Pd, Sn, Hf, Ta, W and Bi or a plurality of the substances is used for the non-magnetic layer, the reliability is enhanced because the element thus added can adsorb the element such as oxygen that may promote the change of the current characteristic with passage of time. Also, when Ti, Ir, V, Zn, Pd, Sn, Hf, Ta, W, Pt, Pb, Bi or C is added to Cu, it is anticipated that these elements function to moderate the interfacial diffusion of the Cu to the magnetic layer.

In addition, among the antiferromagnetic materials, a single substance selected from NiO, CoO, FeO, Fe_2O_3, MnO and CrO, a mixture thereof, or a material prepared by adding to the substance or mixture Mo, W, V, Ir, Nb, Ta, Mn, Tc, Re, Ru, Rh, Fe, Co, Ni, Pt, Pd, Au, Ag or Cu is stable in the air because the main component thereof is an oxide. The single substance of Cr and Mn, a mixture thereof or a material prepared by adding to the substance or mixture Mo, W, V, Ir, Nb, Ta, Mn, Tc, Re, Ru, Rh, Fe, Co, Ni, Pt, Pd, Au, Ag or Cu is stable in the air because both Mn and Cr are materials which are comparatively hardly oxidized although the main component is metal.

When a single-layered film or a multi-layered film formed of Ta, Hf, Si, Au, Pt, Ag, Cu, Mn, Ti, Cr, Al, Si nitride, Si oxides, Al oxide, Al nitride, SiC, C or diamond-like carbon, or a mixture or alloy of these substances is used as a protective layer on the outermost layer, the protective layer functions to prevent the magnetic layer, non-magnetic layer, and antiferromagnetic layer from being in contact with the air. Therefore, the reliability of the spin valve film can be securely obtained even when a material that may comparatively be oxidized easily is used for the magnetic layer, non-magnetic layer, and antiferromagnetic layer.

When a crystalline material is used for the magnetic layer and non-magnetic layer, the combination of substrate and buffer layer affects the crystallinity of the material although its degree depends on the material to be used. If the single substance of Si_3N_4, SiO_2, AlN and Al_2O_3, a mixture thereof, a laminated film or glass is used for the substrate, it is effective to use a single-layered film or a multi-layered film formed of the single substance of Au, Pt, Ag, Cu, Ti, Mn, Cr and Al or a mixture thereof for the buffer layer. When a plastic such as polycarbonate, vinyl chloride, polyimide, polyolefin, and a mixture or laminated film of these materials is used for the substrate, it is possible to obtain the similar effect as in the case where the single substance of Si_3N_4, SiO_2, AlN, Al_2O_3 and glass or a mixture thereof and a laminated film is used for a substrate if a single substance of silicon oxides, silicon nitride, aluminum oxide, aluminum nitride, other ceramics, glass, a mixture thereof, or a laminated film is formed on the substrate as a first buffer layer, and further thereon, a single-layered film or a multi-layered film formed of a single substance of Au, Pt, Ag, Cu, Ti, Mn, Cr and Al or a mixture thereof is provided as a second buffer layer. On the other band, when an amorphous material such as CoZrNb and CoZrMo is used for the magnetic layer, it is possible to use for the buffer layer the single substance of Au, Pt, Ag, Cu, Ti, Mn, Cr, Al, silicon oxides, silicon nitride, aluminum oxide, aluminum nitride, other ceramics, glass, SiC, C, diamond-like carbon and the like, a mixture, or laminated film thereof because the buffer layer is not required to provide properties that may promote the crystallinity of the film.

If the film thickness of the magnetic layer is too small, it becomes difficult to allow a good inversion of spin to take place following the impression of the magnetic field. On the contrary, if it is too large, the magnitude of the coupled magnetic field becomes too small because the magnitude of the coupled magnetic field of the exchange coupling film is proportional to the film thickness. As a result, there is an appropriate range for setting a film thickness.

If the film thickness of the non-magnetic layer is too small, the exchange coupling between the first magnetic layer and the second magnetic layer becomes too strong. Therefore, it becomes difficult for the second magnetic layer to generate its inversion. On the contrary, if it is too large, the MR ratio of the spin valve film is lowered because the rate of dependency of the diffusion of electron in the direction of magnetization becomes small on the interface between the magnetic layer and non-magnetic layer. As a result, there is an appropriate range for setting a film thickness.

When a conductive protective layer and a conductive buffer layer are used, the electric resistance of the spin valve film is lowered as a whole, thus lowering the amount of change in the magnetoresistance if the film thickness is too large. The film thickness of the conductive protective layer and the buffer layer should not be too large.

If the non-conductive protective layer and buffer layer are used, it may be possible to make the film thickness larger than a certain extent because the amount of change in the magnetoresistance is not affected even when the film thickness is large. There are better cases where the film thickness is made larger to a certain extent taking the reliability and the crystal growth into consideration.

BRIEF DESCRIPTION OF THE DRAWINGS

The features of the present invention that are believed to be novel are set forth with particularity in the appended claims. The invention, together with objects and advantages thereof, may best be understood by reference to the following description of the presently preferred embodiments together with the accompanying drawings, in which:

Fig. 1 is a conceptional view showing a spin valve film according to the present invention;
Fig. 2 is a conceptional view showing a spin valve film according to the present invention;
Fig. 3 is a conceptional view showing a spin valve film according to the present invention;
Fig. 4 is a conceptional view showing a spin valve film according to the present invention;
Fig. 5 is a conceptional view showing a spin valve film according to the present invention;
Fig. 6 is a conceptional view showing a spin valve film according to the present invention;
Fig. 7 is a conceptional view showing a spin valve film according to the present invention; and
Fig. 8 is a conceptional view showing a spin valve film according to the present invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

The present invention will be described below in detail by way of Examples.

Example 1

In a structure shown in Fig. 1, a spin valve film was produced by changing the composition of the first magnetic layer and second magnetic layer as shown in Table 1, and using the antiferromagnetic layer of (1), (2) or (3) given below. Then, the inverted magnetic field and the rate of change of the magnetoresistance of the second magnetic layer were measured.

Next, using this spin valve film, a shield reproducing head and a yoke reproducing head were produced to conduct reading tests on a magnetic domain having a width of 0.3 μm recorded on a commercially available hard disk by use of an inductive head. The inverted magnetic field, the rate of change of the magnetoresistance, and the value of reproducing output of the second magnetic layer in this case are shown in each table. The same magnetic domain was reproduced by use of the conventional MR head to give the reproducing signal of 260 μV. Thus, the reproducing signal presented an improvement of two to four times.

(1) In the case where NiO is used for the antiferromagnetic layer:
a spin valve film was produced using glass as the substrate, silicon nitride as the buffer layer (10 nm), Cu as the non-magnetic layer (3 nm), NiO as the antiferromagnetic layer (30 nm) and copper as the protective layer (2 nm) and by changing the composition of the first and second magnetic layers as shown in Table 1 while their film thickness being made 15 nm in these cases. The result of measurement is also shown in Table 1.

Table 1

(2) In the case where FeMn is used for the antiferromagnetic layer:
a spin valve film was produced using glass as the substrate, silicon nitride as the buffer layer (10 nm), Cu as the non-magnetic layer (3 nm), FeMn as the antiferromagnetic layer (10 nm) and copper as the protective layer (2 nm) and by changing the composition of the first and second magnetic layers as shown in Table 2 while their film thickness being made 15 nm in these cases. The result of measurement is also shown in Table 2.

Table 2

(3) In the case where a mixture of CoO and Nio is used for the antiferromagnetic layer:
a spin valve film was produced using Al_2O_3 glass as the substrate, TA as the buffer layer (15 nm), Ag as the non-magnetic layer (3 nm), a mixture of CoO and NiO as the antiferromagnetic layer (40 nm) and copper as the protective layer (2 nm) and by changing the composition of the first and second magnetic layers as shown in Table 3 while their film thickness being made 12 nm and 16 nm, respectively. The result of measurement is also shown in Table 3.

Table 3

Example 2

In the structure shown in Fig. 1, a spin valve film was produced by changing the composition of the non-magnetic layer and using the first and second magnetic layers of (1) and (2) given below. Then, the

inverted magnetic field and the rate of change of magnetoresistance of the second magnetic layer were measured. Also, in the same manner as in Example 1, the inverted magnetic field, the rate of change of magnetoresistance, and the value of reproducing output of the second magnetic layer of shield and yoke reproducing heads were measured.

(1) In the case where FeSiAl is used for both the first and second magnetic layers:

a spin valve film was produced using SiO_2 as the substrate, Hf nitride as the buffer layer (10 nm), FeSiAl as the first magnetic layer (15 nm), FeSiAl as the second magnetic layer (20 nm) and a mixture of FeO, NiO and CoO as the antiferromagnetic layer (35 nm), and copper as the protective layer (2 nm) and by changing the composition of the non-magnetic layer as shown in Table 4 while its film thickness being made 3 nm in these cases. The result of measurement is also shown in Table 4.

Table 4

(2) In the case where FeSiAl is used for the first magnetic layer and NiFe for the second magnetic layer:

a spin valve film was produced using SiO_2 as the substrate, Al nitride as the buffer layer (10 nm), FeSiAl as the first magnetic layer (15 nm), NiFe as the second magnetic layer (13 nm), FeMn as the antiferromagnetic layer (8 nm) and copper as the protective layer (3 nm) and by changing the composition of the non-magnetic layer as shown in Table 5 while its film thickness being made 3 nm in these cases. The result of measurement is also shown in Table 5.

Table 5

Example 3

In the structure shown in Fig. 1, a spin valve film was produced by changing the composition of the antiferromagnetic layer and using the first and second magnetic layers of (1) and (2) given below. Then, the inverted magnetic field and the rate of change of magnetoresistance of the second magnetic layer were measured. Also, in the same manner as in Example 1, the inverted magnetic field, the rate of change of magnetoresistance, and the value of reproducing output of the second magnetic layer of shield and yoke reproducing heads were measured.

(1) In the case where FeSiAl is used for the first magnetic layer and CoZrNb for the second magnetic layer:

a spin valve film was produced using glass as the substrate, Au as the buffer layer (8 nm), FeSiAl as the first magnetic layer (10 nm), Al as the non-magnetic layer (2.5 nm), CoZrNb as the second magnetic layer (16 nm) and copper as the protective layer (2 nm) and by changing the composition of the antiferromagnetic layer as shown in Table 6 while its film thickness being made 12 nm in these cases. The result of measurement is also shown in Table 6.

Table 6

(2) In the case where FeSiAl is used for the first magnetic layer and NiFeCo for the second magnetic layer:

a spin valve film was produced using glass as the substrate, Si_2O_3 as the buffer layer (11 nm), FeSiAl as the first magnetic layer (16 nm), Ag as the non-magnetic layer (3.5 nm), NiFe as the second magnetic layer (14 nm) and Ag as the protective layer (2 nm) and by changing the composition of the antiferromagnetic layer as shown in Table 7 while its film thickness being made 18 nm in these cases. The result of measurement is also shown in Table 7.

Table 7

Example 4

In the structure shown in Fig. 1, a spin valve film was produced by using the antiferromagnetic layer of (1) or (2) given below and changing the elements to be added thereto. Then, the inverted magnetic field and the rate of change of magnetoresistance of the second magnetic layer were measured. Also, in the same manner as in Example 1, the inverted magnetic field, the rate of change of magnetoresistance, and the value of reproducing output of the second magnetic layer of shield and yoke reproducing heads were measured.

(1) In the case where elements are added to the FeMn antiferromagnetic layer:

a spin valve film was produced using glass as the substrate, Pt as the buffer layer (15 nm), FeSiAl as the first magnetic layer (15 nm), Cu as the non-magnetic layer (2.5 nm), NiFe as the second magnetic layer (16 nm) and Ag as the protective layer (2 nm) and by adding various elements to the FeMn antiferromagnetic layer (12 nm) as shown in Table 8. The result of measurement is also shown in Table 8.

Table 8

(2) In the case where elements are added to the NiO antiferromagnetic layer:

a spin valve film was produced using glass as the substrate, a glass-sputtered film as the buffer layer (20 nm), NiFe as the first magnetic layer (20 nm), Ag as the non-magnetic layer (3 nm), NiFe as the second magnetic layer (20 nm) and Cu as the protective layer (2 nm) and by adding various elements to the NiO antiferromagnetic layer (17 nm) as shown in Table 9. The result of measurement is also shown in Table 9.

Table 9

Example 5

In the structure shown in Fig. 1, a spin valve film was produced by changing the composition of the buffer layer and using the first and second magnetic layers of (1) and (2) given below. Then, the inverted magnetic field and the rate of change of magnetoresistance of the second magnetic layer were measured. Also, in the same manner as in Example 1, the inverted magnetic field, the rate of change of magnetoresistance, and the value of reproducing output of the second magnetic layer of shield and yoke reproducing heads were measured.

(1) In the case where the first magnetic layer is NiFe, and the second magnetic layer is FeSiAl:

a spin valve film was produced using glass as the substrate, NiFe as the first magnetic layer (15 nm), Al as the non-magnetic layer (3 nm), FeSiAl as the second magnetic layer (15 nm), FeMn as the antiferromagnetic layer (15 nm) and copper as the protective layer (2 nm) and by changing the composition of the buffer layer as shown in Table 10 while its film thickness being made 15 nm in these cases. The result of measurement is also shown in Table 10.

Table 10

(2) In the case where the first magnetic layer is NiFe and the second magnetic layer is CoZrNb:

a spin valve film was produced using glass as the substrate, NiFe as the first magnetic layer (15 nm), Cu as the non-magnetic layer (3 nm), CoZrNb as the second magnetic layer (15 nm), NiO as the antiferromagnetic layer (15 nm) and copper as the protective layer (2 nm) and by changing the composition of the buffer layer as shown in Table 11 while its film thickness being made 15 nm in these cases. The result of measurement is also shown in Table 11.

Table 11

Example 6

In the structure shown in Fig. 1, a spin valve film was produced by changing the composition of the protective layer and using the antiferromagnetic layer of (1) and (2) given below. Then, the inverted magnetic field, and the rate of change of magnetoresistance of the second magnetic layer were measured. Also, in the same manner as in Example 1, the inverted magnetic field, the rate of change of magnetoresistance, and the value of reproducing output of the second magnetic layer of shield and yoke reproducing heads were measured.

(1) In the case where NiO is used for the antiferromagnetic layer:

a spin valve film was produced using glass as the substrate, Hf as the buffer layer (10 nm), FeSiAl as the first magnetic layer (15 nm), Cu as the non-magnetic layer (3 nm), FeSiAl as the second magnetic layer (15 nm) and NiO as the antiferromagnetic layer (15 nm) and by changing the composition and thickness of the protective layer as shown in Table 12. The result of measurement is also shown in Table 12.

Table 12

(2) In the case where FeMn is used for the antiferromagnetic layer:

a spin valve film was produced using glass as the substrate, SiO_2 as the buffer layer (10 nm), NiFe as the first magnetic layer (12 nm), Cu as the non-magnetic layer (3 nm), NiFe as the second magnetic layer (16 nm) and FeMn as the antiferromagnetic layer (15 nm) and by changing the composition and thickness of the protective layer as shown in Table 13. The result of measurement is also shown in Table 13.

Table 13

Example 7

In the structure shown in Fig. 1, a spin valve film was produced by changing the material of the substrate and using the buffer layer of (1) and (2) given below. Then, the inverted magnetic field and the

rate of change of magnetoresistance of the second magnetic layer were measured. Also, in the same manner as Example 1, the inverted magnetic field, the rate of change of magnetoresistance, and the value of reproducing output of the second magnetic layer of shield and yoke reproducing heads were measured.

(1) In the case where Hf is used for the buffer layer:

a spin valve film was produced using Hf as the buffer layer (10 nm), FeSiAl as the first magnetic layer (17 nm), Cu as the non-magnetic layer (3 nm), FeSiAl as the second magnetic layer (17 nm), NiO as the antiferromagnetic layer (15 nm) and Cu as the protective layer (2 nm) and by changing the composition of the substrate as shown in Table 14. The result of measurement is also shown in Table 14.

Table 14

(2) In the case where Si_3N_4 is used for the buffer layer:

a spin valve film was produced using Si_3N_4 as the buffer layer (80 nm), NiFe as the first magnetic layer (14 nm), Cu as the non-magnetic layer (3 nm), NiFe as the second magnetic layer (14 nm), FeMn as the antiferromagnetic layer (15 nm) and Si_3N_4 as the protective layer (80 nm) and by changing the composition of the substrate as shown in Table 15. The result of measurement is also shown in Table 15.

Table 15

Example 8

In each of the elemental structures of the spin valve film shown in Fig. 1 to Fig. 8, the inverted magnetic field and the rate of change of magnetoresistance of 5.5% were measured for the second magnetic layer by use of the first and second magnetic layers of (1) and (2) given below.

Then, a shield reproducing head and a yoke reproducing head were produced using the respective spin valve films, and the reading tests were performed on the magnetic domain having a width of 0.3 µm recorded on a commercially available hard disk by use of an inductive head.

(1) In the case where the first magnetic layer is CoZrMo and the second magnetic layer is CoZrNb:

(a) When a spin valve film was produced in the structure as shown in Fig. 1 using Al_2O_3 as the substrate, Ta as the buffer layer (10 nm), CoZrMo as the first magnetic layer (15 nm), Cu as the non-magnetic layer (3.5 nm), CoZrNb as the second magnetic layer (15 nm), NiO as the antiferromagnetic layer (50 nm) and Cu as the protective layer (2 nm), there were obtained the inverted magnetic field of 30e and the rate of change of magnetoresistance of 5.5% for the second magnetic layer. The reproducing output value of the shield reproducing head and that of the yoke reproducing head were 890 µV and 960 µV, respectively.

(b) When a spin valve film was produced in the structure as shown in Fig. 2 using Al_2O_3 as the substrate, CoZrMo as the first magnetic layer (15 nm), Cu as the non-magnetic layer (3.5 nm), CoZrNb as the second magnetic layer (15 nm) and NiO as the antiferromagnetic layer (50 nm), there were obtained the inverted magnetic field of 10e and the rate of change of magnetoresistance of 5% for the second magnetic layer. The reproducing output value of the shield reproducing head and that of the yoke reproducing head were 870 µV and 920 µV, respectively.

(c) When a spin valve film was produced in the structure as shown in Fig. 3 using Al_2O_3 as the substrate, CoZrMo as the first magnetic layer (15 nm), Cu as the non-magnetic layer (3.5 nm), CoZrNb as the second magnetic layer (15 nm), NiO as the antiferromagnetic layer (50 nm) and Cu as the protective layer (2 nm), there were obtained the inverted magnetic field of 20e and the rate of change of magnetoresistance of 6% for the second magnetic layer. The reproducing output value of the shield reproducing head and that of the yoke reproducing head were 910 µV and 940 µV, respectively.

(d) When a spin valve film was produced in the structure as shown in Fig. 4 using Al_2O_3 as the substrate, Ta as the buffer layer (10 nm), CoZrMo as the first magnetic layer (15 nm), Cu as the non-magnetic layer (3.5 nm), CoZrNb as the second magnetic layer (15 nm) and NiO as the antiferromagnetic layer (50 nm), there were obtained the inverted magnetic field of 20e and the rate of change of magnetoresistance of 6% for the second magnetic layer. The reproducing output value of the shield reproducing head and that of the yoke reproducing head were 920 µV and 960 µV, respectively.

(e) When a spin valve film was produced in the structure as shown in Fig. 5 using Al_2O_3 as the substrate, CoZrMo as the first magnetic layer (15 nm), Cu as the non-magnetic layer (3.5 nm) and NiO as the antiferromagnetic layer (50 nm), there were obtained the inverted magnetic field of 20e and the rate of change of magnetoresistance of 5% for the second magnetic layer. The reproducing output value of the shield reproducing head and that of the yoke reproducing head were 830 µV and 880 µV, respectively.

(f) When a spin valve film was produced in the structure as shown in Fig. 6 using Al_2O_3 as the substrate, Ta as the buffer layer (10 nm), CoZrMo as the first magnetic layer (15 nm), Cu as the non-magnetic layer (3.5 nm), CoZrNb as the second magnetic layer (15 nm) and NiO as the antiferromagnetic layer (50 nm), there were obtained the inverted magnetic field of 20e and the rate of change of magnetoresistance of 5.5% for the second magnetic layer. The reproducing output value of the shield reproducing head and that of the yoke reproducing head were 870 μV and 860 μV, respectively.

(g) When a spin valve film was produced in the structure as shown in Fig. 7 using Al_2O_3 as the substrate, CoZrMo as the first magnetic layer (15 nm), Cu as the non-magnetic layer (3.5 nm), CoZrNb as the second magnetic layer (15 nm), NiO as the antiferromagnetic layer (50 nm) and Cu as the protective layer (2 nm), there were obtained the inverted magnetic field of 20e and the rate of change of magnetoresistance of 5.5% for the second magnetic layer. The reproducing output value of the shield reproducing head and that of the yoke reproducing head were 870 μV and 860 μV, respectively.

(h) When a spin valve film was produced in the structure as shown in Fig. 8 using Al_2O_3 as the substrate, Ta as the buffer layer (10 nm), CoZrMo as the first magnetic layer (15 nm), Cu as the non-magnetic layer (3.5 nm), CoZrNb as the second magnetic layer (15 nm), NiO as the antiferromagnetic layer (50 nm) and Cu as the protective layer (2 nm), there were obtained the inverted magnetic field of 30e and the rate of change of magnetoresistance of 6% for the second magnetic layer. The reproducing output value of the shield reproducing head and that of the yoke reproducing head were 890 μV and 940 μV, respectively.

(2) In the case where both of the first and second magnetic layers are NiFe:

(a) When a spin valve film was produced in the structure as shown in Fig. 1 using glass as the substrate, Hf as the buffer layer (10 nm), NiFe as the first magnetic layer (15 nm), Ag as the non-magnetic layer (3 nm), NiFe as the second magnetic layer (15 nm) NiO as the antiferromagnetic layer (15 nm) and Cu as the protective layer (2 nm), there were obtained the inverted magnetic field of 20e and the rate of change of magnetoresistance of 6.5% for the second magnetic layer. The reproducing output value of the shield reproducing head and that of the yoke reproducing head were 830 μV and 870 μV, respectively.

(b) When a spin valve film was produced in the structure as shown in Fig. 2 using glass as the substrate, NiFe as the first magnetic layer (15 nm), Ag as the non-magnetic layer (3 nm), NiFe as the second magnetic layer (15 nm) and NiO as the antiferromagnetic layer (15 nm), there were obtained the inverted magnetic field of 20e and the rate of change of magnetoresistance of 5.5% for the second magnetic layer. The reproducing output value of the shield reproducing head and that of the yoke reproducing head were 770 μV and 840 μV, respectively.

(c) When a spin valve film was produced in the structure as shown in Fig. 3 using glass as the substrate, NiFe as the first magnetic layer (15 nm), Ag as the non-magnetic layer (3 nm), NiFe as the second magnetic layer (15 nm), NiO as the antiferromagnetic layer (15 nm) and Cu as the protective layer (2 nm), there were obtained the inverted magnetic field of 40e and the rate of change of magnetoresistance of 6% for the second magnetic layer. The reproducing output value of the shield reproducing head and that of the yoke reproducing head were 690 μV and 750 μV, respectively.

(d) When a spin valve film was produced in the structure as shown in Fig. 4 using glass as the substrate, Hf as the buffer layer (10 nm), NiFe as the first magnetic layer (15 nm), Ag as the non-magnetic layer (3 nm), NiFe as the second magnetic layer (15 nm) and NiO as the antiferromagnetic layer (15 nm), there were obtained the inverted magnetic field of 20e and the rate of change of magnetoresistance of 5.5% for the second magnetic layer. The reproducing output value of the shield reproducing head and that of the yoke reproducing head were 800 μV and 810 μV, respectively.

(e) When a spin valve film was produced in the structure as shown in Fig. 5 using glass as the substrate, NiFe as the first magnetic layer (15 nm), Ag as the non-magnetic layer (3 nm), NiFe as the second magnetic layer (15 nm) and NiO as the antiferromagnetic layer (15 nm), there were obtained the inverted magnetic field of 50e and the rate of change of magnetoresistance of 5% for the second magnetic layer. The reproducing output value of the shield reproducing head and that of the yoke reproducing head were 680 μV and 740 μV, respectively.

(f) When a spin valve film was produced in the structure as shown in Fig. 6 using glass as the substrate, Hf as the buffer layer (10 nm), NiFe as the first magnetic layer (15 nm), Ag as the non-magnetic layer (3 nm), NiFe as the second magnetic layer (15 nm) and NiO as the antiferromagnetic layer (15 nm), there were obtained the inverted magnetic field of 60e and the rate of change of magnetoresistance of 5% for the second magnetic layer. The reproducing output value of the shield reproducing head and that of the yoke reproducing head were 720 μV and 750 μV, respectively.

(g) When a spin valve film was produced in the structure as shown in Fig. 7 using glass as the substrate, NiFe as the first magnetic layer (15 nm), Ag as the non-magnetic layer (3 nm), NiFe as the second magnetic layer (15 nm), NiO as the antiferromagnetic layer (15 nm) and Cu as the protective layer (2 nm), there were obtained the inverted magnetic field of 7Oe and the rate of change of magnetoresistance of 5.5% for the second magnetic layer. The reproducing output value of the shield reproducing head and that of the yoke reproducing head were 810 μV and 830 μV, respectively.

(h) When a spin valve film was produced in the structure as shown in Fig. 8 using glass as the substrate, Hf as the buffer layer (10 nm), NiFe as the first magnetic layer (15 nm), Ag as the non-magnetic layer (3 nm), NiFe as the second magnetic layer (15 nm), NiO as the antiferromagnetic layer (15 nm) and Cu as the protective layer (2 nm), there were obtained the inverted magnetic field of 4Oe and the rate of change of magnetoresistance of 5.5% for the second magnetic layer. The reproducing output value of the shield reproducing head and that of the yoke reproducing head were 760 μV and 840 μV, respectively.

Example 9

In the structure as shown in Fig. 1, a spin valve film was produced by using the first magnetic layer of (1) or (2) given below and changing its film thickness. A shield reproducing head and a yoke reproducing head were manufactured by use of this spin valve film. Then, reading tests were performed on the magnetic domain having a width of 0.3 μm recorded on a commercially available hard disk by use of an inductive head.

(1) In the case where FeSiAl is used for the first magnetic layer:

a spin valve film was produced using glass as the substrate, Hf as the buffer layer (10 nm), Cu as the non-magnetic layer (3 nm), FeSiAl as the second magnetic layer (17 nm), NiO as the antiferromagnetic layer (15 nm) and Cu as the protective layer (2 nm) and by changing the film thickness of the FeSiAl first magnetic layer as shown in Table 16. The values of the reproducing output are also shown in Table 16.

Table 16

(2) In the case where NiFe is used for the first magnetic layer:

a spin valve film was produced using glass as the substrate, SiO_2 as the buffer layer (80 nm), Cu as the non-magnetic layer (3 nm), NiFe as the second magnetic layer (15 nm), FeMn as the antiferromagnetic layer (15 nm) and SiO_2 as the protective layer (80 nm) and by changing the film thickness of the NiFe first magnetic layer as shown in Table 17. The values of the reproducing output are also shown in Table 17.

Table 17

Example 10

In the structure as shown in Fig. 1, a spin valve film was produced by using the second magnetic layer of (1) or (2) given below and changing its film thickness. The values of reproducing outputs of a shield reproducing head and a yoke reproducing head were measured in the same manner as in Example 9.

(1) In the case where CoZrNb is used for the second magnetic layer:

a spin valve film was produced using glass as the substrate, Ta as the buffer layer (10 nm), Cu as the non-magnetic layer (3 nm), CoZrMo as the first magnetic layer (15 nm), NiO as the antiferromagnetic layer (15 nm) and Cu as the protective layer (2 nm) and by changing the film thickness of the CoZrMb second magnetic layer as shown in Table 18. The values of the reproducing outputs of the shield and yoke reproducing heads are also shown in Table 18, respectively.

Table 18

(2) In the case where NiFe is used for the second magnetic layer:

a spin valve film was produced using glass as the substrate, Al_2O_3 as the buffer layer (30 nm), Cu as the non-magnetic layer (3 nm), NiFe as the first magnetic layer (15 nm), FeMn as the antiferromagnetic layer (15 nm) and Al_2O_3 as the protective layer (50 nm) and by changing the film thickness of the NiFe second magnetic layer as shown in Table 19. The values of the reproducing outputs of the shield and yoke reproducing heads are also shown in Table 19, respectively.

Table 19

Example 11

In the structure as shown in Fig. 1, a spin valve film was produced by using the non-magnetic layer of (1) or (2) given below and changing its film thickness. The values of reproducing outputs of a shield reproducing head and a yoke reproducing head were measured in the same manner as in Example 9.

(1) In the case where Cu is used for the non-magnetic layer:

a spin valve film was produced using glass as the substrate, Cr as the buffer layer (10 nm), NiFe as the first magnetic layer (17 nm), FeSiAl as the second magnetic layer (15 nm), NiO as the antiferromagnetic layer (15 nm) and Cu as the protective layer (2 nm) and by changing the film thickness of the Cu non-magnetic layer as shown in Table 20. The values of the reproducing outputs of the shield and yoke reproducing heads are also shown in Table 20, respectively.

Table 20

(2) In the case where Al is used for the non-magnetic layer:

a spin valve film was produced using glass as the substrate, AlN as the buffer layer (30 nm), CoZrMo as the first magnetic layer (17 nm), FeSiAl as the second magnetic layer (15 nm), FeMn as the antiferromagnetic layer (15 nm) and SiO_2 as the protective layer (30 nm) and by changing the film thickness of the Al non-magnetic layer as shown in Table 21. The values of the reproducing outputs of the shield and yoke reproducing heads are also shown in Table 21, respectively.

Table 21

Example 12

In the structure as shown in Fig. 1, a spin valve film was produced by using the antiferromagnetic layer of (1) or (2) given below and changing its film thickness. The values of reproducing outputs of a shield reproducing head and a yoke reproducing head were measured in the same manner as in Example 9.

(1) In the case where FeMn is used for the antiferromagnetic layer:

a spin valve film was produced using glass as the substrate, Ta as the buffer layer (10 nm), NiFe as the first magnetic layer (18 nm), Cu as the non-magnetic layer (3 nm), NiFe as the second magnetic layer (14 nm) and Cu as the protective layer (2 nm) and by changing the film thickness of the FeMn ferromagnetic layer as shown in Table 22. The values of the reproducing outputs of the shield and yoke reproducing heads are also shown in Table 22, respectively.

Table 22

(2) In the case where a mixture of NiO, CoO, and FeO is used for the antiferromagnetic layer:

a spin valve film was produced using glass as the substrate, Pt as the buffer layer (10 nm), FeSiAl as the first magnetic layer (16 nm), Ag as the non-magnetic layer (3 nm), NiFe as the second magnetic layer (18 nm) and Pt as the protective layer (2 nm) and by changing the film thickness of the ferromagnetic layer formed of NiO, CoO and FeO as shown in Table 23. The values of the reproducing outputs of the shield and yoke reproducing heads are also shown in Table 23, respectively.

Table 23

Example 13

In the structure as shown in Fig. 1, a spin valve film was produced by using the metallic protective layer of (1) or (2) given below and changing its film thickness. The values of reproducing outputs of a shield reproducing head and a yoke reproducing head were measured in the same manner as in Example 9.

(1) In the case where Cu is used for the metallic protective layer:

a spin valve film was produced using glass as the substrate, Mo as the buffer layer (10 nm), NiFe as the first magnetic layer (15 nm), Cu as the non-magnetic layer (3 nm), NiFe as the second magnetic layer (15 nm), FeMn as the antiferromagnetic layer (15 nm) and Cu as the protective layer and by changing the film thickness of the Cu protective layer as shown in Table 24. The values of the reproducing outputs of the shield and yoke reproducing heads are also shown in Table 24, respectively.

Table 24

(2) In the case where an AgTi alloy is used for the metallic protective layer:

a spin valve film was produced using glass as the substrate, Si_3N_4 as the buffer layer (50 nm), SiAlTi as the first magnetic layer (13 nm), Au as the non-magnetic layer (3 nm), NiFe as the second magnetic layer (15 nm), FeMn as the antiferromagnetic layer (15 nm) and AgTi alloy as the protective layer and by changing the film thickness of the AgTi alloy protective layer as shown in Table 25. The values of the reproducing outputs of the shield and yoke reproducing heads are also shown in Table 25, respectively.

Table 25

Example 14

In the structure as shown in Fig. 1, a spin valve film was produced by using the non-metallic protective layer of (1) or (2) given below and changing its film thickness. The values of reproducing outputs of a shield reproducing head and a yoke reproducing head were measured in the same manner as in Example 9.

(1) In the case where Si_3N_4 is used for the non-metallic protective layer:

a spin valve film was produced in the structure shown in Fig. 1 using glass as the substrate, Si_3N_4 as the buffer layer (80 nm), NiFe as the first magnetic layer (15 nm), Cu as the non-magnetic layer (3 nm), NiFe as the second magnetic layer (15 nm), FeMn as the antiferromagnetic layer (15 nm) and Si_3N_4 as the protective layer and by changing the film thickness of the Si_3N_4 protective layer as shown in Table 26. The values of the reproducing outputs of the shield and yoke reproducing heads are also shown in Table 26, respectively.

Even when the film thickness of the protective layer is varied as described above, there are almost no changes in the head reproducing outputs. However, if the film thickness is made less than 2 nm, the FeMn antiferromagnetic layer is conspicuously oxidized, thus causing a problem with respect to reliability.

Table 26

(2) In the case where an Al_2O_3 alloy is used for the non-metallic protective layer:

a spin valve film was produced using glass as the substrate, Al_2O_3 as the buffer layer (80 nm), FeSiAl as the first magnetic layer (14 nm), Cu as the non-magnetic layer (3 nm), NiFe as the second magnetic layer (16 nm), FeMn as the antiferromagnetic layer (15 nm) and Al_2O_3 as the protective layer and by changing the film thickness of the Al_2O_3 protective layer as shown in Table 27. The values of the reproducing outputs of the shield and yoke reproducing heads are also shown in Table 27, respectively.

Even when the film thickness of the protective layer is varied as described above, almost no changes are found in the head reproducing outputs. However, if the film thickness is made less than 2 nm, there is a tendency that the FeMn antiferromagnetic layer is conspicuously oxidized.

Table 27

Example 15

In the structure as shown in Fig. 1, a spin valve film was produced by using the metallic buffer layer of (1) or (2) given below and changing its film thickness. The values of reproducing outputs of a shield reproducing head and a yoke reproducing head were measured in the same manner as in Example 9.

(1) In the case where a CuPtAuAg alloy is used for the metallic buffer layer:

a spin valve film was produced using glass as the substrate, CuptAuAg alloy as the buffer layer, NiFe as the first magnetic layer (15 nm), Cu as the non-magnetic layer (3 nm), NiFe as the second magnetic layer (15 nm), FeMn as the antiferromagnetic layer (15 nm) and Si_3N_4 as the protective layer (50 nm) and by changing the film thickness of the CuPtAuAg alloy buffer layer as shown in Table 28. The values of the reproducing outputs of the shield and yoke reproducing heads are also shown in Table 28, respectively.

Table 28

(2) In the case where Ta is used for the metallic buffer layer:

a spin valve film was produced using glass as the substrate, Ta as the buffer layer, CoZrMo as the first magnetic layer (15 nm), Ag as the non-magnetic layer (3 nm), NiFe as the second magnetic layer (15 nm), FeMn as the antiferromagnetic layer (15 nm) and Si_3N_4 as the protective layer (50 nm) and by changing the film thickness of the buffer layer as shown in Table 29. The values of the reproducing outputs of the shield and yoke reproducing heads are also shown in Table 29, respectively.

Table 29

Example 16

In the structure as shown in Fig. 1, a spin valve film was produced by using the non-metallic buffer layer of (1) or (2) given below and changing its film thickness. The values of reproducing outputs of a shield reproducing head and a yoke reproducing head were measured in the same manner as in Example 9.

(1) In the case where Si_3N_4 is used for the metallic buffer layer:

a spin valve film was produced using SiO_2 as the substrate, Si_3N_4 as the buffer layer, NiFe as the first

magnetic layer (15 nm), Cu as the non-magnetic layer (3 nm), NiFe as the second magnetic layer (15 nm), FeMn as the antiferromagnetic layer (15 nm) and Si_3N_4 as the protective layer (50 nm) and by changing the film thickness of the buffer layer as shown in Table 30. The values of the reproducing outputs of the shield and yoke reproducing heads are also shown in Table 30, respectively.

Table 30

(2) In the case where a mixture of SiO_2, Si_3N_4, AlN, and Al_2O_3 is used for the non-metallic buffer layer: a spin valve film was produced using garnet as the substrate, a mixture of SiO_2, Si_3N_4, AlN and Al_2O_3 as the buffer layer, FeSi as the first magnetic layer (15 nm), Cu as the non-magnetic layer (3 nm), NiFe as the second magnetic layer (15 nm), FeMn as the antiferromagnetic layer (15 nm) and AlN as the protective layer (60 nm) and by changing the film thickness of the buffer layer as shown in Table 31. The values of the reproducing outputs of the shield and yoke reproducing heads are also shown in Table 31, respectively.

Table 31

Example 17

In the structure as shown in Fig. 1, the magnetic layers were formed under the conditions of (1) to (5) given below. The inverted magnetic field and the rate of change of the magnetoresistance of the second magnetic layer were measured.

Then, a shield reproducing head and a yoke reproducing head were manufactured by use of a spin valve film thus produced. Reading tests were performed on the magnetic domain having a width of 0.3 μm recorded on a commercially available hard disk by use of an inductive head. Then, the values of reproducing output were obtained.

(1) In the case where a double-layered film is used for the first magnetic layer:
When a spin valve film was produced using Al_2O_3 as the substrate, Ti as the buffer layer (10 nm), a double-layered film of CoZrMo (5 nm)/CoZrNb (10 nm) as the first magnetic layer, Cu as the non-magnetic layer (3.5 nm), CoZrNb as the second magnetic layer (15 nm), NiO as the antiferromagnetic layer (15 nm) and Cu as the protective layer (2 nm), there were obtained the inverted magnetic field of 1Oe and the rate of change of magnetoresistance of 7% for the second magnetic layer. The reproducing output value of the shield reproducing head and that of the yoke reproducing head were 930 μV and 970 μV, respectively.

(2) In the case where an eight-layered film is used for the first magnetic layer:
When a spin valve film was produced using Al_2O_3 as the substrate, Ti as the buffer layer (10 nm), an eight-layered film of (CoZrMo (2 nm)/CoZrNb (2 nm)) x 4 as the first magnetic layer, Cu as the non-magnetic layer (3 nm), CoZrNb as the second magnetic layer (15 nm), NiO as the antiferromagnetic layer (15 nm) and Cu as the protective layer (2 nm), there were obtained the inverted magnetic field of 1Oe and the rate of change of magnetoresistance of 8% for the second magnetic layer. The reproducing output value of the shield reproducing head and that of the yoke reproducing head were 1070 μV and 1130 μV, respectively.

(3) In the case where a three-layered film is used for the second magnetic layer:
When a spin valve film was produced using glass as the substrate, W as the buffer layer (10 nm), FeSiAl as the first magnetic layer (15 nm), Cu as the non-magnetic layer (3 nm), a three-layered film of FeNi (5 nm)/FeSiAl (5 nm)/FeSi (5 nm) as the second magnetic layer, FeMn as the antiferromagnetic layer (15 nm) and Cu as the protective layer (2 nm), there were obtained the inverted magnetic field of 1Oe and the rate of change of magnetoresistance of 6.5% for the second magnetic layer. The reproducing output value of the shield reproducing head and that of the yoke reproducing head were 910 μV and 940 μV, respectively.

(4) In the case where a 16-layered film is used for the second magnetic layer:
When a spin valve film was produced using glass as the substrate, W as the buffer layer (10 nm), FeSiAl as the first magnetic layer (15 nm), Cu as the non-magnetic layer (3 nm), a 16-layered film of (FeNi (1 nm)/FeSiAl (1 nm)) x 8 as the second magnetic layer, FeMn as the antiferromagnetic layer (15 nm) and Cu as the protective layer (2 nm), there were obtained the inverted magnetic field of 1Oe and the rate of change of magnetoresistance of 7% for the second magnetic layer. The reproducing output value of the shield reproducing head and that of the yoke reproducing head were 950 μV and 930 μV, respectively.

(5) In the case where a 16-layered film is used for the first magnetic layer and another 16-layered film is used for the second magnetic layer:
When a spin valve film was produced using glass as the substrate, Si_3N_4 as the buffer layer (80 nm), a 16-layered film of (NiFe (1 nm)/FeSiAl (1 nm)) x 8 as the first magnetic layer, Cu as the non-magnetic

layer (3 nm), a 16-layered film of (FeNi (1 nm)/FeSiAl (1 nm)) x 8 for the second magnetic layer, FeMn as the antiferromagnetic layer (15 nm) and Cu as the protective layer (2 nm), there were obtained the inverted magnetic field of 1Oe and the rate of change of magnetoresistance of 9% for the second magnetic layer. The reproducing output value of the shield reproducing head and that of the yoke reproducing head were 1270 µV and 1300 µV, respectively.

Example 18

In the structure shown in Fig. 1, the non-magnetic layers were formed under the conditions of (1) and (2) given below. The inverted magnetic field and the rate of change of the magnetoresistance of the second magnetic layer were measured. Also, the reproducing output value of the shield reproducing head and that of the yoke reproducing head were measured in the same manner as in Example 17.

(1) In the case where a double-layered film is used for the non-magnetic layer:

When a spin valve film was produced using glass as the substrate, Si_3N_4 as the buffer layer (80 nm), a 16-layered film of (NiFe (1 nm)/FeSiAl (1 nm)) x 8 as the first magnetic layer, a double-layered film of Au (1.5 nm)/Ag (1.5 nm) as the non-magnetic layer, a 16-layered film of (FeNi (1 nm)/FeSiAl (1 nm)) x 8 as the second magnetic layer, FeMn as the antiferromagnetic layer (15 nm) and Cu as the protective layer, there were obtained the inverted magnetic field of 1Oe and the rate of change of magnetoresistance of 9.5% of the second magnetic layer. The reproducing output value of the shield reproducing head and that of the yoke reproducing head were 1290 µV and 1330 µV, respectively.

(2) In the case where a three-layered film is used for the non-magnetic layer:

When a spin valve film was produced using glass as the substrate, Si_3N_4 as the buffer layer (80 nm), a 16-layered film of (NiFe (1 nm)/FeSiAl (1 nm)) x 8 as the first magnetic layer, a three-layered film of Ag (1 nm)/Cu (1 nm)/Ag (1 nm) as the non-magnetic layer, a 16-layered film of (FeNi (1 nm)/FeSiAl (1 nm)) x 8 as the second magnetic layer, FeMn as the antiferromagnetic layer (15 nm) and Cu as the protective layer (2 nm), there were obtained the inverted magnetic field of 1Oe and the rate of change of magnetoresistance of 9.5% of the second magnetic layer. The reproducing output value of the shield reproducing head and that of the yoke reproducing head were 1270 µV and 1310 µV, respectively.

Example 19

In the structure shown in Fig. 1, the antiferromagnetic layers were formed under the conditions of (1) and (2) given below. The inverted magnetic field and the rate of change of the magnetoresistance of the second magnetic layer were measured. Also, the reproducing output value of the shield reproducing head and that of the yoke reproducing head were measured in the same manner as in Example 17.

(1) In the case where a double-layered film is used for the antiferromagnetic layer:

When a spin valve film was produced using glass as the substrate, Hf as the buffer layer (10 nm), NiFe as the first magnetic layer (15 nm), Cu as the non-magnetic layer (3 nm), FeNi as the second magnetic layer (15 nm), a double-layered film of NiO (10 nm)/CoO (10 nm) as the antiferromagnetic layer and Cu as the protective layer (2 nm), there were obtained the inverted magnetic field of 2Oe and the rate of change of magnetoresistance of 7.5%. The reproducing output value of the shield reproducing head and that of the yoke reproducing head were 910 µV and 920 µV, respectively.

(2) In the case where a three-layered film is used for the antiferromagnetic layer:

When a spin valve film was produced using glass as the substrate, Hf as the buffer layer (10 nm), FeSiAl as the first magnetic layer (15 nm), Pt as the non-magnetic layer (3 nm), FeNi as the second magnetic layer (15 nm), a three-layered film of NiO (5 nm)/FeMn (5 nm)/NiO (5 nm) as the antiferromagnetic layer and Cu as the protective layer (2 nm), there were obtained the inverted magnetic field of 2Oe and the rate of change of magnetoresistance of 8%. The reproducing output value of the shield reproducing head and that of the yoke reproducing head were 970 µV and 940 µV, respectively.

Example 20

In the structure shown in Fig. 1, the buffer layers were formed under the conditions of (1) and (2) given below. The inverted magnetic field and the rate of change of the magnetoresistance of the second magnetic layer were measured. Also, the reproducing output value of the shield reproducing head and that of the yoke reproducing head were measured in the same manner as in Example 17.

(1) In the case where a double-layered film is used for the buffer layer:

When a spin valve film was produced using polycarbonate as the substrate, a double-layered film of

Si_3N_4 (50 nm)/Hf (10 nm) as the buffer layer, NiFe as the first magnetic layer (15 nm), Cu as the non-magnetic layer (3 nm), FeNi as the second magnetic layer (15 nm), a double-layered film of NiO (10 nm)/CoO (10 nm) as the antiferromagnetic layer and Cu as the protective layer (2 nm), there were obtained the inverted magnetic field of 10e and the rate of change of magnetoresistance of 8% of the second magnetic layer. The reproducing output value of the shield reproducing head and that of the yoke reproducing head were 980 μV and 960 μV, respectively.

(2) When a three-layered film is used for the buffer layer:

When a spin valve film was produced using polycarbonate as the substrate, a three-layered film of Si_3N_4 (50 nm)/Hf (5 nm)/Ta (5 nm) as the buffer layer, NiFe as the first magnetic layer (15 nm), Cu as the non-magnetic layer (3 nm), FeNi as the second magnetic layer (15 nm), a double-layered film of NiO (10 nm)/CoO (10 nm) as the antiferromagnetic layer and Cu as the protective layer (2 nm), there were obtained the inverted magnetic field of 10e and the rate of change of magnetoresistance of 9% of the second magnetic layer. The reproducing output value of the shield reproducing head and that of the yoke reproducing head were 1260 μV and 1290 μV, respectively.

Example 21

In the structure shown in Fig. 1, the protective layers were formed under the conditions of (1) and (2) given below. The inverted magnetic field and the rate of change of the magnetoresistance of the second magnetic layer were measured. Also, the reproducing output value of the shield reproducing head and that of the yoke reproducing head were measured in the same manner as in Example 17.

(1) In the case where a double-layered film is used for the protective layer:

When a spin valve film was produced using glass as the substrate, a double-layered film of Si_3N_4 (50 nm)/Hf (10 nm) as the buffer layer, Cu as the non-magnetic layer (3 nm), FeNi as the second magnetic layer (15 nm), NiO as the antiferromagnetic layer (15 nm) and a double-layered film of Cu (2 nm)/Si_3N_4 - (50 nm) as the protective layer, there were obtained the inverted magnetic field of 10e and the rate of change of magnetoresistance of 8% of the second magnetic layer. The reproducing output value of the shield reproducing head and that of the yoke reproducing head were 970 μV and 950 μV, respectively.

(2) When a three-layered film is used for the protective layer:

When a spin valve film was produced using glass as the substrate, a double-layered film of Si_3N_4 (50 nm)/Hf (10 nm) as the buffer layer, NiFe as the first magnetic layer (15 nm), Cu as the non-magnetic layer (3 nm), FeNi as the second magnetic layer (15 nm), FeMn as the antiferromagnetic layer (15 nm) and a three-layered film of Cu (2 nm)/Si_3N_4 (50 nm)/an ultraviolet-curing resin (500 nm) as the protective layer, there were obtained the inverted magnetic field of 10e and the rate of change of magnetoresistance of 8% of the second magnetic layer. The reproducing output value of the shield reproducing head and that of the yoke reproducing head were 950 μV and 950 μV, respectively.

Example 22

In the structure shown in Fig. 1, the substrates of the following conditions (1) and (2) were used to measure the inverted magnetic field and the rate of change of the magnetoresistance of the second magnetic layer. Also, the reproducing output value of the shield reproducing head and that of the yoke reproducing head were measured in the same manner as in Example 17.

(1) In the case where a double-layered substrate is used:

When a spin valve film was produced using glass/SiO_2 as the substrate, Hf as the buffer layer (10 nm), NiFe as the first magnetic layer (15 nm), Cu as the non-magnetic layer (3 nm), FeNi as the second magnetic layer (15 nm), NiO as the antiferromagnetic layer (15 nm) and Cu as the protective layer (2 nm), there were obtained the inverted magnetic field of 10e and the rate of change of magnetoresistance of 7% of the second magnetic layer. The reproducing output value of the shield reproducing head and that of the yoke reproducing head were 920 μV and 950 μV, respectively.

(2) In the case where another double-layered substrate is used:

When a spin valve film was produced using glass/UV-curing resin as the substrate, a double-layered film of SiO_2 (70 nm)/Hf (10 nm) as the buffer layer, NiFe as the first magnetic layer (15 nm), Cu as the non-magnetic layer (3 nm), FeNi as the second magnetic layer (15 nm), NiO as the antiferromagnetic layer (15 nm) and Cu as the protective layer (2 nm), there were obtained the inverted magnetic field of 10e and the rate of change of magnetoresistance of 7% of the second magnetic layer. The reproducing output value of the shield reproducing head and that of the yoke reproducing head were 940 μV and 910 μV, respectively.

As described above, according to the application of the present invention, a thin film having a good sensitivity with respect to magnetic field and a significant magneto-esistive effect can be obtained. When using this thin film for a shield reproducing head or a yoke reproducing head, the maximum reproducing output obtainable is approximately four times that of a reproducing head which utilizes the magnetoresistive effect provided by the application of the prior art.

According to the invention a spin valve film is disclosed having a first magnetic layer, a non-magnetic layer, a second magnetic layer and an antiferromagnetic layer as the fundamental structure for the film. In such structure of the spin valve film, a single-layered film or a multi-layered film consisting of CoZrNb, CoZrMo, FeSiAl or FeSi, or a material prepared by adding Cr, Mn, Pt, Ni, Cu, Ag, Al, Ti, Fe, Co or Zn to the above-mentioned substance is used for at least one of the first magnetic layer and second magnetic layer. According to the present invention, a thin spin valve film having a good sensitivity with respect to magnetic field and a significant magnetoresistive effect can be obtained. When using this thin film for a shield reproducing head or a yoke reproducing head, the maximum reproducing output obtainable is approximately four times that of a reproducing head which utilizes the magnetoresistive effect provided by the application of the prior art.

[Table 1]

First magnetic layer	Second magnetic layer	Second magnetic layer inverted magnetic field (Oe)	Rate of change in magnetoresistance	Shield head reproducing output (μV)	Yoke head reproducing output (μV)
CoZrNb	CoZrNb	1	4	800	740
CoZrMo	CoZrMo	1	3.5	730	690
FeSiAl	FeSiAl	2	5	940	920
FeSi	FeSi	10	5	570	490
NiFe	NiFe	2	4	770	730
NiFe	FeSiAl	2	5	980	910
FeSiAl	NiFe	2	4	790	770
NiFe	CoZrNb	1	4	880	810
FeSiAl	CoZrNb	3	4	760	720
CoZrNb	CoZrMo	1	4.5	1050	970

[Table 2]

First magnetic layer	Second magnetic layer	Second magnetic layer inverted magnetic field (Oe)	Rate of change in magnetoresistance	Shield head reproducing output (μV)	Yoke head reproducing output (μV)
CoZrNb	CoZrNb	2	5	930	860
CoZrMo	CoZrMo	1	3.5	810	670
FeSiAl	FeSiAl	3	6	1070	980
FeSi	FeSi	9	5	670	570
NiFe	NiFe	2	4.5	820	770
NiFe	FeSiAl	3	4.5	970	920
FeSiAl	NiFe	1	4	870	810
NiFe	CoZrNb	2	4	870	820
FeSiAl	CoZrNb	4	5	790	790
CoZrNb	CoZrMo	2	4.5	1070	1060

[Table 3]

First magnetic layer	Second magnetic layer	Second magnetic layer inverted magnetic field (Oe)	Rate of change in magnetoresistance	Shield head reproducing output (μV)	Yoke head reproducing output (μV)
CoZrNb	CoZrNb	1	4	870	900
CoZrMo	CoZrMo	1	3	800	820
FeSiAl	FeSiAl	2	7	900	930
FeSi	FeSi	10	5	650	670
NiFe	NiFe	2	4	790	810
NiFe	FeSiAl	1	4	930	990
FeSiAl	NiFe	1	4.5	880	940
NiFe	CoZrNb	1	3.5	870	870
FeSiAl	CoZrNb	3	4	810	860
CoZrNb	CoZrMo	1	4	990	1070

[Table 4]

Non-magnetic layer	Second magnetic layer inverted magnetic field (Oe)	Rate of change in magnetoresistance	Shield head reproducing output (μV)	Yoke head reproducing output (μV)
Cu	1	5	990	1040
Al	2	4.5	910	1000
Si	4	3.5	810	880
Ti	3	5	850	880
V	3.5	4	790	850
Zn	7	3.5	680	690
Zr	1	4.5	880	990
Nb	10	2	330	380
Mo	3	5.5	910	900
Pd	2	4.5	930	940
Ag	1	6	1100	1130
Sn	5	4	810	860
Hf	2	5	860	920
Ir	1	7	1120	1150
Ta	1	4.5	900	890
W	2	4	890	910
Pt	1	5	960	990
Au	1	7	1270	1330
Pb	10	3	290	310
Bi	20	3.5	220	230
C	9	2	270	300
SiC	7	2.5	260	270

[Table 5]

Non-magnetic layer	Second magnetic layer inverted magnetic field (Oe)	Rate of change in magnetoresistance	Shield head reproducing output (μV)	Yoke head reproducing output (μV)
Cu	3	4	550	590
Al	4	3.5	670	660
Si	5	3	470	460
Ti	7	4	460	420
V	8	3	390	420
Zn	17	3	260	280
Zr	6	3.5	460	490
Nb	25	2.5	170	190
Mo	6	5	670	660
Pd	4	4	720	690
Ag	3	5	820	870
Sn	6	3	680	750
Hf	7	4	620	690
Ta	4	5.5	860	870
W	6	4	790	810
Pt	2	4.5	810	910
Au	5	5	760	750
Pb	16	2.5	280	280
Bi	30	3	140	190
C	12	2.5	160	210
SiC	7	2.5	280	330

[Table 6]

Antiferromagnetic layer	Second magnetic layer inverted magnetic field (Oe)	Rate of change in magnetoresistance	Shield head reproducing output (μV)	Yoke head reproducing output (μV)
FeMn	1	5	880	930
NiO	4	4.5	770	790
NiO + CoO	3	4.5	790	830
NiO + FeO	3	4	820	880
Fe_2O_3	6	3	380	390
MnO	4	4	760	850
CrO	1	6.5	920	960
Cr	3	2.5	460	400
Mn	5	3	490	520

[Table 7]

Antiferromagnetic layer	Second magnetic layer inverted magnetic field (Oe)	Rate of change in magnetoresistance	Shield head reproducing output (μV)	Yoke head reproducing output (μV)
FeMn	2	6	830	800
NiO	3	5.5	810	790
NiO + CoO	2	4.5	770	810
NiO + FeO	4	4	680	760
Fe_2O_3	10	4	480	450
MnO	3	4.5	620	600
CrO	2	5.5	940	930
Cr	4	3.5	570	490
Mn	7	3.5	470	530

[Table 8]

Element added to antiferromagnetic layer	Second magnetic layer inverted magnetic field (Oe)	Rate of change in magnetoresistance	Shield head reproducing output (μV)	Yoke head reproducing output (μV)
Mo	2	5	730	780
W	3	5.5	820	790
V	3	4.5	680	740
Nb	1	5	990	1020
Ta	4	4	680	690
Ir	1	6	1030	1070
Mn	3	4.5	760	750
Tc	2	5.5	870	990
Re	1	4.5	800	780
Ru	3	5	820	790
Rh	2	5	820	770
Fe	2	5.5	810	760
Co	1	6	960	1080
Ni	3	4.5	720	740
Pt	2	5.5	840	900
Pd	3	4.5	780	810
Au	2	5	860	820
Ag	1	5	1000	1120
Cu	1	6	1270	1340

[Table 9]

Element added to antiferromagnetic layer	Second magnetic layer inverted magnetic field (Oe)	Rate of change in magnetoresistance	Shield head reproducing output (μV)	Yoke head reproducing output (μV)
Mo	3	5.5	780	840
W	2	5.5	820	780
V	3	5	740	790
Ir	2	6	890	930
Nb	2	6	890	1030
Ta	3	6	870	990
Mn	2	5.5	850	950
Tc	4	6.5	930	1040
Re	2	5.5	900	1050
Ru	3	5	810	800
Rh	2	6	860	840
Fe	3	5.5	780	800
Co	2	5	810	790
Ni	2	4.5	760	760
Pt	3	5.5	830	840
Pd	2	5	770	840
Au	3	5	770	830
Ag	1	6	1100	1110
Cu	2	6.5	1110	1170

[Table 10]

Buffer layer	Second magnetic layer inverted magnetic field (Oe)	Rate of change in magnetoresistance	Shield head reproducing output (μV)	Yoke head reproducing output (μV)
Ta	2	5	780	750
Hf	3	4.5	770	730
Si	7	3	510	490
Au	4	2	190	180
Pt	8	3	350	360
Ag	4	4	670	730
Cu	8	3.5	470	550
Ti	17	2.5	370	400
Mn	13	3.5	320	330
Cr	14	3	360	390
Al	5	4	680	660
Si_3N_4	2	6	820	930
SiO_2	3	6	840	940
Al_2O_3	2	6.5	910	970
SiC	3	6	870	920
C	10	2.5	250	290
Diamond-like carbon	3	6	910	970

[Table 11]

Buffer layer	Second magnetic layer inverted magnetic field (Oe)	Rate of change in magnetoresistance	Shield head reproducing output (μV)	Yoke head reproducing output (μV)
Ta	1	5.5	820	860
Hf	2	5	810	770
Si	18	3.5	260	310
Au	3	4	720	760
Pt	3	6	820	900
Ag	4	6.5	860	890
Cu	11	3.5	370	350
Ti	15	3	220	270
Mn	14	3.5	280	320
Cr	19	2	170	190
Al	5	6	780	820
Si_3N_4	2	7	1030	1080
SiO_2	3	7	1020	1100
Al_2O_3	2	6.5	1010	1110
SiC	2	7	990	1100
C	12	2.5	220	290
Diamond-like carbon	3	6.5	960	1090

[Table 12]

Protective layer	Thickness (nm)	Second magnetic layer inverted magnetic field (Oe)	Rate of change in magnetoresistance (%)	Shield head reproducing output (μV)	Yoke head reproducing output (μV)
Ta	3	2	5	820	840
Hf	3	3	5.5	810	850
Si	40	3	5	850	860
Au	2	2	5	840	880
Pt	2	2	5.5	810	870
Ag	2	2	6	830	880
Cu	2	2	6	850	900
Ti	3	3	5.5	830	850
Cr	3	3	5	840	840
Al	3	2	5.5	830	860
Si_3N_4	50	2	6	820	930
SiO_2	80	3	6	840	940
Al_2O_3	60	2	6.5	910	970
SiC	20	3	6	870	920
C	30	4	5.5	780	810
Diamond-like carbon	20	3	6.5	830	880
CuTi	3	2	6	840	850
CuPt	3	2	6	810	860
TaTi	3	2	6.5	820	880
PtAu	3	2	6.5	830	880
AgAu	2	2	6	820	860
CuCr	3	3	6	810	870
Si oxide + Al oxide	60	2	6.5	820	890
Si nitride + Al nitride	50	2	6	830	860
Si nitride + Si oxide	60	2	6.5	840	890
Al nitride + Al oxide	80	3	6.5	820	870
Si oxide + Si nitride + Al oxide + Al nitride	50	2	6.5	840	900

[Table 13]

Protective layer	Thickness (nm)	Second magnetic layer inverted magnetic field (Oe)	Rate of change in magneto-resistance (%)	Shield head reproducing output (μV)	Yoke head reproducing output (μV)
Ta	3	2	6	920	970
Hf	3	2	7	1020	1070
Si	40	3	6.5	950	1020
Au	2	2	6.5	970	1110
Pt	2	2	7	1030	1090
Ag	2	3	6.5	900	910
Cu	2	2	7	1090	1130
Ti	3	3	6.5	930	940
Cr	3	3	6.5	940	970
Al	3	2	6	910	960
Si_3N_4	50	2	7	960	1130
SiO_2	80	2	7	990	1170
Al_2O_3	60	3	6.5	910	960
SiC	20	2	7	1100	1180
C	30	5	6	720	750
Diamond-like carbon	20	2	7	900	910
CuTi	3	3	6.5	930	970
CuPt	3	2	6.5	910	980
TaTi	3	3	6	890	950
PtAu	3	2	7	910	960
AgAu	2	2	7	920	990
CuCr	3	3	6.5	820	860
Si oxide + Al oxide	60	2	7	940	960
Si nitride + Al nitride	50	2	7	940	970
Si nitride + Si oxide	60	2	6.5	880	920
Al nitride + Al oxide	80	2	6.5	870	870
Si oxide + Si nitride + Al oxide + Al nitride	50	2	7	940	1040

[Table 14]

Substrate	Second magnetic layer inverted magnetic field (Oe)	Rate of change in magnetoresistance (%)	Shield head reproducing output (μV)	Yoke head reproducing output (μV)
Glass	2	5.5	830	870
SiO_2	3	6	920	990
Si_3N_4	2	5.5	850	880
AlN	2	7	1010	1130
Al_2O_3	2	6.5	910	940
SiO_2 + Si_3N_4	3	6.5	930	970
AlN + Al_2O_3	2	6.5	940	970
Si_3N_4 + Al_2O_3	3	7	990	1070
Si_3N_4 + AlN	2	6.5	910	950
SiO_2 + Al_2O_3 + Si_3N_4 + AlN	3	7	940	1040
Al	2	7	680	650
Cu	3	7.5	690	660
W	2	7	850	830
Ti	2	7	840	810
Mo	2	7.5	880	810
NiCr alloy	3	7	890	840
Zn	2	7	880	850
CuZn alloy	2	7	860	830
TiAl alloy	2	6.5	780	780
Polycarbonate	8	4.5	430	470
Vinyl chloride	14	4	380	390
Polyimide	5	5	760	790
Polyolefin	7	4.5	510	550
Polycarbonate + polyolefin	6	5.5	680	720

[Table 15]

Substrate	Second magnetic layer inverted magnetic field (Oe)	Rate of change in magnetoresistance (%)	Shield head reproducing output (μV)	Yoke head reproducing output (μV)
Glass	2	6.5	820	860
SiO_2	2	7	960	980
Si_3N_4	3	6.5	790	810
AlN	2	7.5	950	980
Al_2O_3	3	7	970	1040
SiO_2 + Si_3N_4	2	7	970	1030
AlN + Al_2O_3	2	7	940	1010
Si_3O_2 + Al_2O_3	3	7.5	980	1090
Si_3N_4 + AlN	2	7	920	940
SiO_2 + Al_2O_3 + Si_3N_4 + AlN	2	7.5	1010	1040
Al	2	8	920	990
Cu	3	7.5	910	1010
W	2	7	890	930
Ti	2	7.5	930	1030
Mo	3	7	900	960
NiCr alloy	3	7	890	960
Zn	2	6.5	810	850
CuZn alloy	2	7	870	910
TiAl alloy	2	7	920	960
Polycarbonate	5	6	630	680
Vinyl chloride	8	5	580	610
Polyimide	3	6	770	780
Polyolefin	5	5	610	680
Polycarbonate + polyolefin	6	6	710	760

[Table 16]

Film thickness of first magnetic layer (nm)	Shield head reproducing output (μV)	Yoke head reproducing output (μV)
0	0	0
5	590	470
10	900	780
15	920	850
20	890	860
25	850	840
30	820	800
35	710	750
40	600	680
45	470	570

[Table 17]

Film thickness of first magnetic layer (nm)	Shield head reproducing output (μV)	Yoke head reproducing output (μV)
0	0	0
5	420	380
10	750	690
15	880	790
20	960	860
25	880	850
30	810	810
35	680	750
40	510	650
45	360	520

[Table 18]

Film thickness of first magnetic layer (nm)	Shield head reproducing output (μV)	Yoke head reproducing output (μV)
0	0	0
5	470	420
10	770	720
15	920	880
20	910	950
25	850	870
30	720	810
35	600	740
40	440	650
45	210	470

[Table 19]

Film thickness of second magnetic layer (nm)	Shield head reproducing output (μV)	Yoke head reproducing output (μV)
0	0	0
5	690	560
10	880	740
15	900	960
20	780	820
25	690	720
30	560	600
35	410	480
40	260	320
45	190	220

[Table 20]

Film thickness of nonmagnetic layer (nm)	Shield head reproducing output (μV)	Yoke head reproducing output (μV)
0	0	0
0.5	0	0
1.0	0	0
1.5	260	300
2.0	780	810
2.5	880	890
3.0	920	930
3.5	890	880
4.0	740	770
4.5	690	650
5.0	520	510

[Table 21]

Film thickness of nonmagnetic layer (nm)	Shield head reproducing output (μV)	Yoke head reproducing output (μV)
0	0	0
0.5	0	0
1.0	0	0
1.5	320	330
2.0	750	790
2.5	840	880
3.0	930	950
3.5	870	840
4.0	760	720
4.5	640	600
5.0	490	470

[Table 22]

Film thickness of antiferromagnetic layer (nm)	Shield head reproducing output (μV)	Yoke head reproducing output (μV)
0	0	0
10	880	890
20	900	890
50	870	860
100	850	840
200	830	810
500	780	760
1000	720	730

[Table 23]

Film thickness of antiferromagnetic layer (nm)	Shield head reproducing output (μV)	Yoke head reproducing output (μV)
0	0	0
10	780	770
20	840	860
50	870	880
100	840	850
200	820	820
500	800	790
1000	780	750

[Table 24]

Film thickness of Cu protective layer (nm)	Shield head reproducing output (μV)	Yoke head reproducing output (μV)
0	920	940
0.5	910	950
1.0	920	930
1.5	900	900
2.0	900	920
2.5	890	910
3.0	850	880
3.5	820	840
4.0	760	790
4.5	720	750
5.0	680	690

[Table 25]

Film thickness of AgTi alloy protective layer (nm)	Shield head reproducing output (μV)	Yoke head reproducing output (μV)
0	970	930
0.5	960	950
1.0	960	940
1.5	940	920
2.0	950	900
2.5	920	910
3.0	920	870
3.5	880	810
4.0	790	760
4.5	710	710
5.0	650	630

[Table 26]

Film thickness of Si_3N_4 protective layer (nm)	Shield head reproducing output (μV)	Yoke head reproducing output (μV)
0	920	940
1	910	950
2	920	930
5	900	940
10	920	920
20	910	950
50	920	950
100	920	940

[Table 27]

Film thickness of Al_2O_3 protective layer (nm)	Shield head reproducing output (μV)	Yoke head reproducing output (μV)
0	930	940
1	940	940
2	930	950
5	940	930
10	920	920
20	940	940
50	920	930
100	930	920

[Table 28]

Film thickness of CuPtAuAg alloy buffer layer (nm)	Shield head reproducing output (μV)	Yoke head reproducing output (μV)
0	920	950
5	910	940
10	910	940
15	890	920
20	860	850
25	810	810
30	760	720
35	700	660

[Table 29]

Film thickness of Ta alloy buffer layer (nm)	Shield head reproducing output (μV)	Yoke head reproducing output (μV)
0	850	870
5	840	840
10	830	840
15	810	800
20	780	750
25	740	720
30	690	680
35	640	630

[Table 30]

Film thickness of Si_3N_4 buffer layer (nm)	Shield head reproducing output (μV)	Yoke head reproducing output (μV)
0	780	790
5	820	830
10	850	860
15	880	890
20	890	890
25	910	910
30	900	900
35	890	890

[Table 31]

Film thickness of buffer layer (nm)	Shield head reproducing output (μV)	Yoke head reproducing output (μV)
0	740	760
5	830	840
10	860	870
15	850	860
20	870	890
25	860	880
30	880	870
35	860	890

Claims

1. A spin valve film comprising a first magnetic layer, a non-magnetic layer, a second magnetic layer, and an antiferromagnetic layer as the fundamental structure for the film, wherein a single-layered film or a multi-layered film consisting of CoZrNb, CoZrMo, FeSiAl or FeSi is used for at least one of said first magnetic layer and second magnetic layer.

2. The spin valve film according to Claim 1, wherein a single-layered film or a multi-layered film formed of a single substance selected from Al, Si, Ti, Ir, V, Cu, Zn, Zr, Nb, Mo, Pd, Ag, Sn, Hf, Ta, W, Pt, Au, Pb, Bi, C and silicon carbide or a mixture thereof is used for said non-magnetic layer.

3. The spin valve film according to Claim 1 or 2, wherein a single-layered film or a multi-layered film formed of a single substance selected from FeMn, NiO, CoO, FeO, Fe_2O_3, MnO, CrO, Cr and Mn or a mixture thereof or a material prepared by adding to the substance or mixture Mo, W, V, Ir, Nb, Ta, Mn, Tc, Re, Ru, Rh, Fe, Co, Ni, Pt, Pd, Au, Ag or Cu is used as said antiferromagnetic layer.

4. The spin valve film according to any of Claims 1 to 3, wherein a single-layered film or a multi-layered film formed of a material to which Cr, Mn, Pt, Ni, Ir, Cu, Ag, Al, Ti, Fe, Co or Zn is added is used for said first or second magnetic layer.

5. A spin valve film comprising a first magnetic layer, a non-magnetic layer, a second magnetic layer, and an antiferromagnetic layer as the fundamental structure for the film, wherein at least one of said first magnetic layer and said second magnetic layer is formed of NiFe or NiFeCo, and a single-layered film or a multi-layered film formed of a single substance selected from Al, Si, Ti, Ir, V, Zn, Zr, Nb, Mo, Pd, Ag, Sn, Hf, Ta, W, Pt, Au, Pb, Bi, C and silicon carbide or a mixture thereof is used for said non-magnetic layer.

6. The spin valve film according to Claim 5, wherein a single substance selected from CoO, FeO, Fe_2O_3, MnO, CrO, Cr and Mn or a mixture thereof, or a single-layered film or a multi-layered film of a material prepared by adding to the substance or mixture Mo, W, V, Ir, Nb, Ta, Mn, Tc, Re, Ru, Rh, Fe, Co, Ni, Pt, Pd, Au, Ag or Cu is used as said antiferromagnetic layer.

7. The spin valve film according to any of Claims 1 to 6, wherein said first magnetic layer or said antiferromagnetic layer is in contact with a substrate or a buffer layer formed on the substrate.

8. The spin valve film according to Claim 7, wherein a protective layer is formed on the outermost layer.

9. The spin valve film according to Claim 7 or 8, wherein at least one of said first magnetic layer and said second magnetic layer is formed of CoZrNb, CoZrMo, FeSiAl, FeSi, NiFe or NiFeCo, and a single-layered film or a multi-layered film formed of glass, ceramic, metal, metal compound or plastic or a mixture thereof is used for said substrate.

10. The spin valve film according to any of Claims 7 to 9, wherein a single-layered film or a multi-layered film formed of a single substance selected from Ta, Hf, Si, Au, Pt, Ag, Cu, Ti, Mn, Or, Al, Si nitride, Si oxides, Al oxide, AlN, Al nitride, SiC and C or a mixture thereof is used for said buffer layer.

11. The spin valve film according to any of Claims 8 to 10, wherein a single-layered film or a multi-layered film formed of Ta, Hf, Si, Au, Pt, Ag, Cu, Mn, Ti, Cr, Al, Si nitride, Si oxides, Al oxide, Al nitride, SiC, C or diamond-like carbon or a mixture or alloy thereof is used for said protective layer.

12. The spin valve film according to any of Claims 1 to 11, wherein the film thickness of at least one of said first magnetic layer and said second magnetic layer is 5 to 30 nm.

13. The spin valve film according to any of Claims 1 to 12, wherein the film thickness of said non-magnetic layer is 2 to 5 nm.

14. The spin valve film according to any of Claims 1 to 13, wherein the film thickness of said antiferromagnetic layer is 10 to 100 nm.

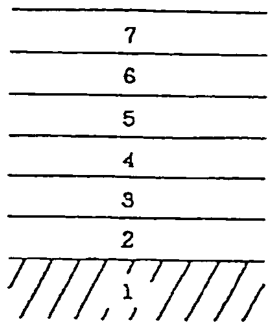
15. The spin valve film according to any of Claims 1 to 14, wherein the film thickness of a metallic protective layer is 3 nm or less.

16. The spin valve film according to any of Claims 1 to 15, wherein the film thickness of a non-metallic protective layer is 2 nm or more.

17. The spin valve film according to any of Claims 1 to 16, wherein the film thickness of a metallic buffer layer is 15 nm or less.

18. The spin valve film according to any of Claims 1 to 17, wherein the film thickness of a non-metallic buffer layer is 5 nm or more.

Fig. 1



1 substrate
2 buffer layer
3 first magnetic layer
4 non-magnetic layer
5 second magnetic layer
6 antiferromagnetic layer
7 protective layer

Fig. 2

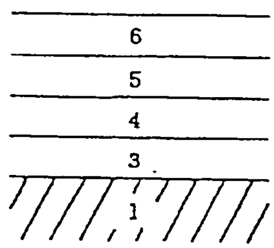


Fig. 3

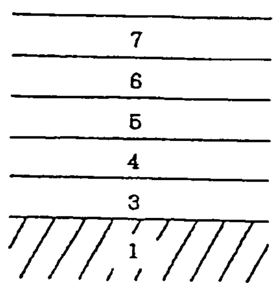


Fig. 4

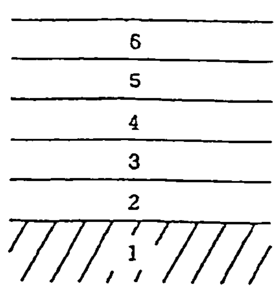


Fig. 5

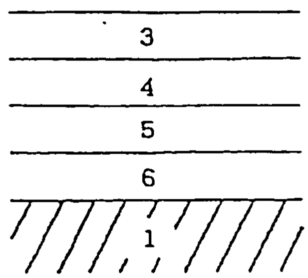


Fig. 6

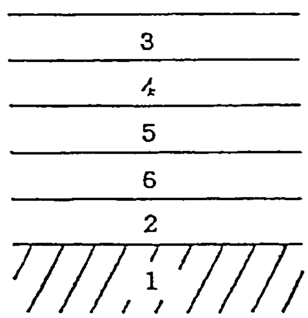


Fig. 7

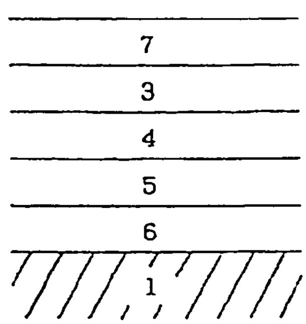
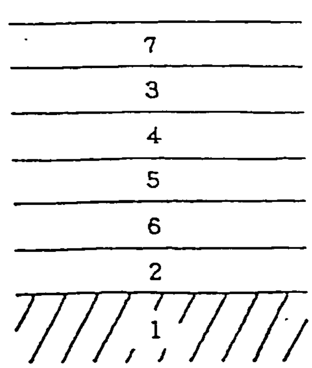


Fig. 8



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Application Number
EP 95 10 3991

Category	DOCUMENTS CONSIDERED TO BE RELEVANT Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int.Cl.6)
Y	JOURNAL OF APPLIED PHYSICS, vol. 64,no. 10, PART 2, pages 5673-5675, XP 000024012 KAMO Y ET AL 'FABRICATION OF AN INDUCTOR USING AMORPHOUS FILMS WITH A MULTILAYERED STRUCTURE' * the whole document * ---	1,7,9	H01F10/08 G11B5/39 G01R33/09 H01L43/10
Y	IEEE TRANSLATION JOURNAL ON MAGNETICS IN JAPAN, vol. 7,no. 12, December 1992 NEW YORK US, pages 969-974, XP 000365006 E.SUGAWARA ET AL	1,7,9	
A	* the whole document * ---	8,11	
X	JOURNAL OF APPLIED PHYSICS, vol. 69,no. 8, 15 April 1991 NEW YORK US, pages 5634-5636, K.K.KUNG ET AL * page 5634 * ---	5,7-9, 11-14	
			TECHNICAL FIELDS SEARCHED (Int.Cl.6)
X	JOURNAL OF APPLIED PHYSICS, vol. 74,no. 10, 15 November 1993 NEW YORK US, pages 6297-6301, S.SOEYA ET AL * page 6297 * ---	5,7-9, 11,12, 14,16	H01F G11B G01R H01L
A	US-A-4 103 315 (R.HEMPSTAED ET AL) * column 11, line 53 - column 13, line 38; claims 1-4,7 * ---	5,7,10	
P,X	PATENT ABSTRACTS OF JAPAN vol. 18 no. 564 (P-1819) ,27 October 1994 & JP-A-06 203336 (NEC CORP.) 22 July 1994, * abstract * -----	1-6	

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
THE HAGUE	29 May 1995	Decanniere, L

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
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